



## Original Articles

# Assessing current monitoring indicators and reporting for cumulative effects integration: A case study in Muskoka, Ontario, Canada

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## ABSTRACT

Climate is changing at an unprecedented rate with impacts being felt in social and ecological systems around the world. Opportunities for building climate resilience of the social-ecological system surrounding freshwater areas are assessed using the aquatic monitoring and reporting programs of Muskoka River Watershed (Ontario, Canada) as a case study. A three-step study design was used: establishment of a knowledge baseline (i.e., what has been done), confirmation of the baseline to ensure perspectives that emerged were inclusive of multiple stakeholders (i.e., broadly applicable) and an exploratory workshop to disseminate recommendations and discuss implementation with key stakeholders. Two themes are discussed: the strengthening of watershed-scale monitoring approaches, and improved communication with stakeholders (e.g., through ‘state of the watershed’ reporting). This study offers an evaluation of watershed-scale aquatic monitoring and reporting and provides concrete examples from the case study. We test a new process for refining, selecting, or prioritizing indicators for aquatic monitoring. Cumulative effects assessment and monitoring (CEAM) is considered as the suggested monitoring approach at a watershed-scale. Recommendations for developing CEAM in the Muskoka River Watershed include considerations for selection of monitoring indicators, consistent communication of indicators, and implementing a metadatabase. Ways to enhance education of, and engagement with, local stakeholders through improved ‘state of the watershed’ report cards are highlighted. Resilience is strengthened by addressing two goals in the case study: engaging with the community and improving knowledge of stressor-effect relationships in the watershed via stronger aquatic monitoring.

## 1. Introduction

Resilience of communities to environmental changes is increasingly a priority as cumulative impacts and changes in climate are becoming increasingly visible (Armitage et al., 2017; Lebel et al., 2006). Climate change threatens resilience in many ways, affecting resource development, causing more frequent devastating storm events (e.g., flooding, fires, drought), interrupting biogeochemical cycles, and increasing the spread of vector-borne diseases (IPCC, 2013). The 100 Resilient Cities global network, pioneered by the Rockefeller Foundation, describes many examples of communities that are focusing on building climate resilience in their economies, communities, and environments, which

demonstrates the growing global interest in resilience in general (100 Resilient Cities, 2017). Arguably, the foundation of (climate) resilient communities is the use of monitoring programs (e.g., monitoring the environment as well as policy outcomes) that inform and increase capacity to implement relevant strategies. Without monitoring programs, decision makers, managers, and local communities would not understand what changes are likely to occur, the implications of these changes or the effectiveness of management measures.

The main objectives of environmental monitoring programs, including monitoring of water and watersheds, are to assess current states, identify change (Anderson et al., 2003), predict risks from potential effects (Brack et al., 2009), and to inform a management

**Abbreviations:** CE, cumulative effects; CEA, cumulative effects assessment; CEAM, cumulative effects assessment and monitoring(/management); COSIA, Canada's Oil Sands Innovation Alliance; CWN, Canadian Water Network; CWRC (or, CWN-CWRC), Canadian Watershed Research Consortium; DMM, District Municipality of Muskoka; HLW, healthy land and water (program – <http://hlw.org.au>); MWC, Muskoka Watershed Council; THREATS, The Healthy River Ecosystem Assessment System, a software by Greenland Group of Companies (consulting firms that focus on civil environmental alternative energy and software engineering, as well as landscape architecture); VEC(s), valued ecosystem component(s); WISKI, water information systems, a software by KISTERS (an international company which specializes in the development of data management software)

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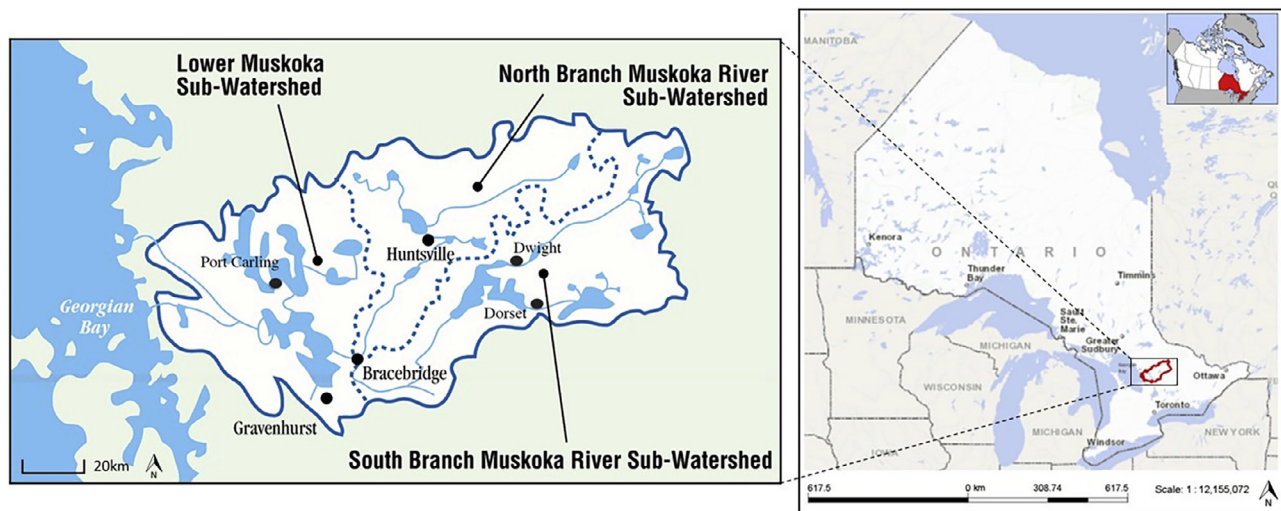


Fig. 1. Map of Muskoka River Watershed in Ontario, Canada. Overlay of Muskoka Watershed provided by Muskoka Watershed Council (MWC, 2016a).

response (Jones, 2016). Water monitoring generally refers to measuring living and/or non-living indicators for water quantity and quality over time. Watershed monitoring incorporates broader indicators that consider implications of land use, climate change, and human activities across a watershed – defined in this paper as the landscape boundary (e.g., high points) surrounding the expanse of land area from and within which water drains to a common outlet. Water management is the practice of balancing social, economic and environmental priorities in decision-making, promoting water use that support these priorities and, in some regions, assisting with or advising in land use planning activities with implications on or from water.

Potential effects in water monitoring include effects from climate change, e.g., changes to amount and frequency of precipitation, different lengths and temporal patterns of seasons, and water-related secondary impacts, e.g., changes in surface water quantity, flows, temperatures and quality. In this way, water monitoring can aid decision makers and water managers in preparing for such potential effects, which in turn increases community resilience. Due to differences in regulatory requirements, water quality standards, land use, and a variety of other biophysical and social dimensions, water management and monitoring must be tailored to the locality (Behmel et al., 2016). As such, each region may choose to incorporate principles of many watershed monitoring approaches, customizing a holistic process for tracking complex environmental change over time.

Cumulative effects assessment and monitoring (CEAM) can integrate components of different watershed monitoring and management approaches, and is applied at a sub-regional, watershed-level. Cumulative effects (CE) are defined as “changes to the biophysical, social, economic, and cultural environments caused by the combination of past, present and ‘reasonably foreseeable’ future actions” (INAC, 2007; Northwest Territories, 2015). Cumulative effects assessment (CEA) emerged from environmental assessment processes with two main objectives: to clarify trends and variability, and to determine causality between stressors and stresses (Ball et al., 2013; Bidstrup et al., 2016). Cumulative effects assessment and monitoring (CEAM) is defined by Dubé (2015, 1) as “the process of monitoring, tracking and predicting accumulating environmental change relative to established limits”.

This study investigates enhancing climate-resilience of communities and ecosystems by improving watershed monitoring in the case study of Muskoka River Watershed in Ontario, Canada. The results and discussion are organized according to the two study objectives: identify opportunities for strengthening watershed monitoring and communicate the state of the watershed with stakeholders (e.g., educate).

### 1.1. Case study: Muskoka River watershed

As in other areas of Canada (and the world), climate change in the region of Muskoka, Ontario has impacted its air, land, and water, affecting drinking water, angling, biodiversity, and recreational activities (Sale et al., 2016). Changes in weather patterns (MWC, 2010) and movement of species ranges (Waite and Strickland, 2006) are already being observed. Although action has been undertaken in Muskoka to improve regional watershed monitoring, formal climate resilience strategies have not been implemented. Despite monitoring watershed indicators (e.g., water flows and temperature, biodiversity, land use) that may point to impacts from climate change, climatic changes and interactions with them are not explicitly monitored. Also, reporting has thus far excluded framing or discussion around climate change. The consideration of climate interactions is a crucial piece to the region’s ability to plan and manage for an increasingly uncertain, potentially volatile, and highly complex future.

The Muskoka River Watershed (Fig. 1) is the largest of four primary watersheds in the Muskoka region. It consists of over 2000 lakes connected by the Muskoka River and its tributaries (Eimers, 2016; Wilson, nd). Its headwaters are in Algonquin Park, flowing southwesterly into Lake Muskoka and then into Georgian Bay (Wilson, nd). At its widest section, it is more than 62 km wide, and it covers an approximate area of 4660 km<sup>2</sup>. There is a small resident population of about 60,599 people (2016 data for District Municipality of Muskoka), though the Muskoka region is used throughout the year by similar numbers of cottagers and outdoor enthusiasts (MWC, 2016a). Seasonal residents slightly outnumber permanent/year-round residents. Communities located in the Watershed include Dwight, Dorset, Huntsville, Bracebridge, Gravenhurst and Port Carling (Wilson, nd). The abundance of scenery and wildlife found in the region attracts a plethora of sportsmen and tourists from across Ontario and the world – including some of Canada’s wealthiest travelers, earning it the nickname among some, ‘Hamptons of the North’ (Pigg, 2015).

In Ontario (and other areas across Canada and abroad), local water resources are managed on a sub-regional scale. The widely-accepted unit of management is the watershed, which typically extends beyond individual municipalities, but is more manageable for day-to-day operations than attempting to manage the whole province, territory, or nation. Often, collaboration between watersheds occurs to tackle larger-scale issues, but implementation of management generally occurs within a single watershed (an exception to this is the Great Lakes system, which is sometimes discussed as an entire system including all five lakes and connecting waterways). The Muskoka Watershed Council

(MWC) is the organization tasked with understanding the health of the Muskoka River Watershed and dispersing this information to residents, managers and decision-makers.

MWC is a volunteer-based, non-regulatory group of government representatives, scientists, and the public from across the Muskoka River Watershed who together strive to provide information to decision-makers and water managers. The five core activities of MWC are: produce Watershed Report Cards (describing the state of the system through ongoing monitoring); develop position papers on issues related to watershed health (e.g., wetlands, aggregates, pesticides, etc.); collaborate with others on projects related to watershed health (e.g., surveys); engage with the public to improve individual awareness and behaviour through Best Practices program; and develop public outreach and education programs (news articles, presentations) (MWC, 2012a).

MWC's mandate is to champion watershed health through watershed evaluation, advising on issues, educating the public, and promoting practices and behaviours that support a sustainable economy, healthy community and resilient watershed (MWC, 2012a). The health of the watershed is determined by monitoring components of the system deemed valuable to stakeholders in the region (e.g., MWC values swimmable lakes). These components are monitored through a set of measures, or indicators, that are observed on an ongoing basis for evidence of change (e.g., presence and levels of *E. coli*). It should be noted that a healthy system may be defined differently in different contexts. For example, clear water is valued in the Muskoka River Watershed, but in the Grand River Watershed, which drains into Lake Erie, clear water is not a realistic determinant of water health due to the sediment make-up of sand, silt, and clay (Water Quality Working Group, 2013).

Although 36 watersheds in Ontario are managed by Conservation Authorities, the Muskoka River Watershed is not. The reasons for this, and its implications, can be understood given historical and procedural context. The creation of Conservation Authorities was first authorized by the *Conservation Authorities Act* in 1946 in response to concerns raised by agricultural, naturalist, and sports groups regarding degraded land, water, and forestry resources, which together led to severe flooding. The Act outlined certain managerial powers to Conservation Authorities, which were amended after Hurricane Hazel (Ontario's most famous rain event, in 1954) to include acquisition of land for recreation and conservation, regulation of that land for community safety, and provision of opportunities for public education and enjoyment while maintaining watershed health. The *Building Better Communities and Conserving Watersheds Act*, S.O. 2017C.23, was recently approved to update the *Conservation Authorities Act*, R.S.O. 1990, c. C.27. The new Act clarifies Conservation Authority roles and responsibilities, strengthens accountability, increases public engagement (e.g., requiring meetings to be open to the public), increases consistency in approaches (e.g., use of integrated watershed management), and modernizes funding mechanisms (Conservation Ontario, 2018).

To form a Conservation Authority, two or more municipalities request its formation, a number of municipal representatives (based on population) from at least two thirds of the involved municipalities meet with the Minister of Natural Resources (and Forestry). The Minister, once satisfied the municipalities represented agree on and are committed to the formation of an Authority (determined by vote), approves the resolution. The Lieutenant Governor in Council may then establish the Authority. The Lieutenant Governor in Council determines the Authority's name and jurisdictional boundaries, including which municipalities are included (in part or whole). Initially, Conservation Authorities were funded by provincial and municipal funds; today, they are primarily funded by municipalities.

It was not until the late 1990s that the Muskoka Heritage Foundation, cofounder of MWC, identified the need to engage with the broader, growing community in watershed issues (MWC, 2012b) – more than 50 years after Conservation Authorities were first established. Since the need for these Authorities arose from a combination of

degradation, growing pressures from increasing populations (e.g., 31 of 36 Conservation Authorities are in Southern Ontario), and flooding, and since funding comes from the municipalities involved, it is not surprising the Muskoka region has pursued other forms of watershed management. In 2001, the Muskoka Heritage Foundation and the District Municipality of Muskoka partnered to form MWC.

MWC differs from a Conservation Authority in several ways. First, it brokers conversations and actions between stakeholders in the region, without management or enforcement powers that Conservation Authorities have. MWC's mandate, activities, and operational boundaries are self-determined. The people involved in MWC do not legally have to represent at least two thirds of the municipalities in the Watershed, nor is there any regulatory requirement for certain co-operation or approvals within those municipalities. MWC is not a provincially-established entity. Thus, certain 'powers' given to Conservation Authorities (e.g., ability to acquire lands and govern development on those lands) are not applicable to MWC, nor are certain accountabilities to the Province (e.g., the new requirement for public disclosure of and access to meetings).

Funding mechanisms are structured differently as well, as municipalities in the Muskoka River Watershed do not have regulatory obligations to fund any activities as municipalities within Conservation Authorities do. Conservation Authorities are required to have dedicated staff, whereas any MWC staff typically add the MWC role onto their existing employment (e.g., as a municipal employee, as opposed to a Conservation Authority employee). As a result, many aspects of MWC's work – especially ongoing activities like monitoring of watershed health – are done in partnership with institutions and organizations that typically also have representation (e.g., volunteers) in MWC.

Previous work supported by MWC (Sale et al., 2016) resulted in 15 recommendations for building a climate-resilient community and environment. This study addresses two recommendations from Sale et al. (2016), which came out of a study to build climate resilience in the region. These recommendations were selected during initial discussions between the researchers and the MWC:

- 1.a. *Strengthen and broaden the existing monitoring of lakes in Muskoka; and*
- 2.a. *Every individual Muskokan should undertake to become informed on climate change issues, and take real steps to reduce his/her own carbon footprint.*

These goals, which improve monitoring programs and engage local communities to act in mutually-beneficial ways, are goals that are frequently incorporated into watershed management planning in other areas of Ontario, across Canada, and elsewhere (Huff and Thomas, 2014; OCCIAR, nd; Pearson and Burton, 2009; Veale, 2010).

Monitoring in the Muskoka River Watershed varies from year to year. For example, in 2015, 84 sites at 70 lakes were monitored for numerous parameters, including total phosphorous and other chemical parameters (total 46), water clarity, dissolved oxygen, water temperature, shoreline land use, progression of denaturalization, benthic macroinvertebrates, and in some cases, terrestrial plot health (e.g., biodiversity, tree cover) (DMM, 2016). Monitoring in 2016, when this study was done, consisted of 85 sites on 68 lakes (DMM, 2016). Monitoring in the Muskoka River Watershed is conducted to achieve the following objectives: preventing algal blooms; preserving biodiversity within the watershed; sustaining recreation, tourism, and economic activities; maintaining community engagement; addressing shoreline development pressures; and, mitigating land use change near water bodies (Ho et al., 2016; Sale et al., 2016). Additionally, the maintenance of water quality in Muskoka's waterbodies is a priority, required for drinking water, angling, biodiversity, and recreation (Eimers, 2016).

The monitoring program methods and results can be found in a detailed report by the District Municipality of Muskoka (DMM, 2016). Information from the monitoring program is published in plain-



language Watershed Report Cards, which are shared with the residents and stakeholders within the watershed approximately every four years. The results of the Report Cards review are in [Section 3.2](#) (Communication). Specific information including fisheries facts, shoreline survey maps, lake data sheets, etc. can be found on the District Municipality's free access water communication website, the Muskoka Water Web. Data are collected, kept, and used by individuals at several institutions, including universities doing research in the area, the DMM, the Ontario Ministry of Natural Resources and Forestry, various community associations, and consultant groups (DMM, 2016).

This study supports MWC's objective to build climate resilience of local communities into its watershed monitoring and reporting programs. Since the two goals – strengthening monitoring and educating the local community – are common goals of other water managers locally and abroad, the approach used in this study is transferrable to other geographical contexts.

## 2. Methods

This study used a three-step design adapted from examples across the literature (Aaker et al., 1998; Erickson, 1986; Flyvbjerg, 2006; Hakim, 2000; McNabb, 2004; Nargundkar, 2008; Shields and Rangarajan, 2013; Stake, 2005; Stebbins, 2001; Reis, nd). The study occurred over eight months, from January to August 2016. It incorporated multiple tools and approaches, including a review of literature, documents, and prior research, personal communication with practitioners and stakeholders, analyses of other examples, and an exploratory workshop in which the new indicator selection process was tested (Aaker et al., 1998; Hakim, 2000; McNabb 2004; Nargundkar, 2008; Shields and Rangarajan, 2013). This approach was used to gain insight into prominent issues with current watershed monitoring and reporting and to generate recommendations that can be immediately useful in developing climate resilient research and practice (McNabb, 2004; Shields and Rangarajan, 2013). The steps used in this study (Fig. 2) include:

1. Establish a knowledge baseline of what has been done and what is currently being done to address climate change or to consider cumulative effects in Canadian monitoring and management programs;
2. Confirm the baseline to ensure perspectives that emerged were inclusive of multiple stakeholders (i.e., broadly applicable); and

3. Hold an exploratory workshop to disseminate recommendations to key stakeholders and engage in discussion regarding implementation (including indicator selection).

While the resources used to collect data in each step were specific to the context of this study, the overall process can be tailored to other contexts.

### 2.1. Step one: establish a knowledge baseline

The authors were the only individuals involved in the first step of the methodology (Fig. 2, Step 1). Literature relating to watershed monitoring and management frameworks was reviewed to provide strategies for considering cumulative effects in climate-vulnerable watersheds. Examples of watershed monitoring in Ontario (including Muskoka River Watershed) and Australia were highlighted, and a national initiative aimed at practicing CEAM was reviewed. Of the literature reviewed, some were sought out by the authors, while others were recommended by MWC.

Literature reviewed focused on two main topics: cumulative effects monitoring in Canada and climate change mitigation and/or adaptation. A number of reports of recent research in cumulative effects were found on the Canadian Water Network (CWN) website: cumulative effects (CE) in Muskoka River Watershed (Eimers, 2016), CE in the Grand River Watershed (Servos, 2016); CE in the Northumberland Strait (van den Heuvel et al., 2016), defining CE in Canada (Dubé, 2015) a *Synthesis of Learnings* of CWN's Canadian Watershed Research Consortium (CWN, 2016a), and a decision support paper (CWN, 2016b). The recent report (Jones, 2016) with recommendations for addressing climate change in the Muskoka River Watershed was found on MWC's website. Peer-reviewed research related to environmental monitoring, environmental assessment, and/or cumulative effects (Arciszewski and Munkittrick, 2014; Ball et al., 2013; Veale, 2010; and others cited in this paper) was also used to supplement our learning and discussion.

As part of the literature review, climate change adaptation plans were reviewed for two other watersheds in Ontario as well: Lake Superior (Huff and Thomas, 2014) and Lake Simcoe (OCCAR, nd). These plans offered insights into potential challenges and opportunities to enhance climate resilience in the Muskoka River Watershed. After a thorough search for climate change plans for Ontario watersheds, the Lake Superior plan (Huff and Thomas, 2014) was selected for its comprehensiveness and the Lake Simcoe plan (OCCAR, nd) due to its

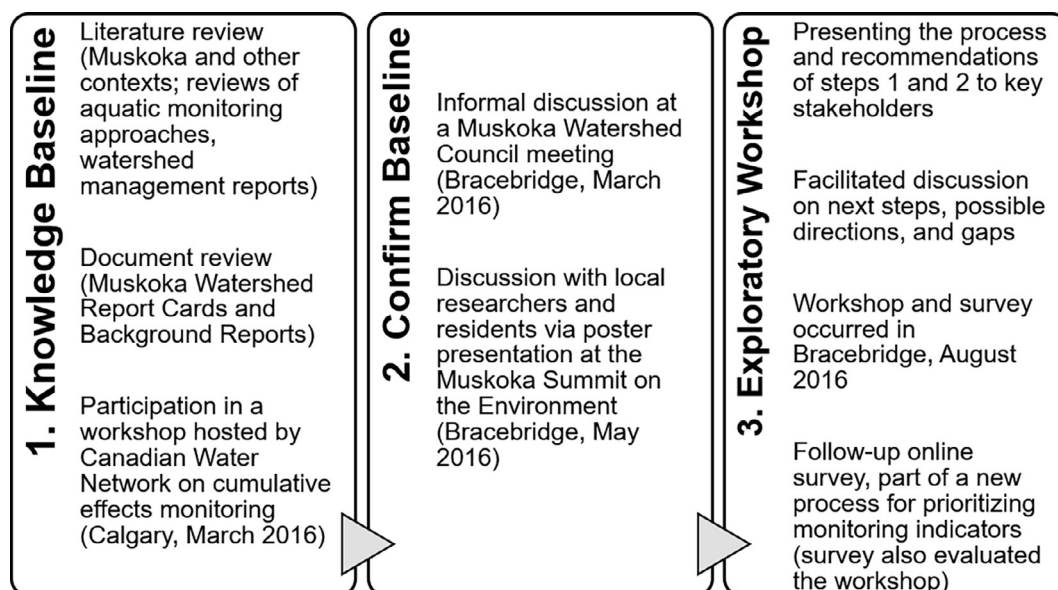


Fig. 2. The three-step study design used in the Muskoka River Watershed case study, with a list of resources used or actions taken in each step.

priority in the view of the province. Further, the Lake Simcoe Watershed was selected by Ontario's Expert Panel on Climate Change as a pilot project for potential province-wide climate adaptation policy and planning (Pearson and Burton, 2009).

The current state of watershed monitoring in Muskoka River Watershed was evaluated during a document review of MWC's monitoring reporting program. Their 'state of the watershed' Report Cards were generated from 2004 to 2014 and were found on their website. The Report Cards (2004, 2007, 2010, 2014) and the Progress Report (2009) were evaluated for the materials' accessibility to the public, their ability to demonstrate trends, and whether watershed reporting was completed in a meaningful way. Accessibility implies the Report Cards were easy for the average community member (target audience) to read and understand, i.e., their layouts and visuals are clear and easy to follow, and that they would make a community member want to pick up and read them (e.g., as opposed to a formal manuscript-style report). Meaningful reporting refers to clear relevance to, and implications for, community members, and engagement with them. For example, does the Report Card inspire critical thinking or reflection? Does it initiate conversation with neighbors? Background Reports were also reviewed for context, consistency, and to assess trends using more detailed, scientific content.

The authors also participated in a workshop in March 2016, co-lead by CWN and Canada's Oil Sands Innovation Alliance (COSIA), titled *Advancing Adaptive Monitoring Strategies to Support Cumulative Effects Decisions* (which produced CWN, 2016b). Participation in this workshop provided insight into current efforts for implementing CEAM. Lessons learned (opportunities and barriers) from the full review process were identified for implementing a cumulative effects monitoring framework in Canadian watersheds.

## 2.2. Step two: confirm baseline

The second step of our methodology (Fig. 2) was also led/carried out by the authors, through engagement with a variety of stakeholders at an MWC council meeting (March 2016), a CWN Canadian Watershed Research Consortium (CWRC) workshop (March 2016), and at a local conference (Muskoka Summit on the Environment; Bracebridge, Ontario; May 2016). It was important to discuss local perspectives with the stakeholders themselves, who could then identify and provide additional resources, perspectives and context missed during the initial literature review.

First, lessons that emerged from watershed monitoring programs Canada-wide were discussed during the CWN-CWRC workshop (a synthesis of learning outcomes from each node can be found at CWN, 2016b). These lessons were considered in the case study. Second, the authors clarified MWC's goals, initiatives and priorities at a Council meeting in March 2016. Scientists, leaders, and practitioners working in the Muskoka River Watershed were involved in this discussion. Third, during ongoing discussion throughout 2016, the feasibility of MWC adopting a cumulative effects assessment and monitoring (CEAM) program was evaluated.

A report (Ho et al., 2016) was submitted to MWC, highlighting identified issues and potential solutions to achieve the two goals in the context of building climate resilience. The report synthesized literature and document reviews and provided insight from the exploratory workshop. This report was used to create two shorter documents: a communications summary for use in MWC's review of its Report Cards program, and a brief newsletter providing summary information to the public. A poster was presented at the Muskoka Summit on the Environment (Bracebridge, Ontario) in May 2016. There, the study was shared with local researchers, residents, cottagers, students, and scientists, and community feedback was collected for consideration moving forward. In addition, outcomes from the review and discussions with stakeholders highlighted a need to develop a different way of selecting monitoring indicators for watershed monitoring in general,

including but not limited to climate change considerations. A new selection method was tested in the exploratory workshop.

## 2.3. Step three: hold an exploratory workshop

The final step of our methodology was to facilitate an exploratory workshop by the authors to disseminate the findings of our study, discuss next steps, and test a new process for prioritizing monitoring indicators (Fig. 2). This workshop was held on August 5, 2016 with MWC in Bracebridge, Ontario. There were 12 workshop participants, including three MWC staff, three members of two local communities, two guests from the Georgian Bay Biosphere Reserve, an academic stakeholder, a regional government stakeholder, a member of the Skeleton Lake Association (Skeleton Lake is part of the Muskoka River Watershed), and an environmental consultant. The Georgian Bay Biosphere Reserve participants presented insights from their recently concluded *State of the Bay* reporting process.

First, conclusions and recommendations of our study's review were presented, feedback from participants was given and discussed, and the process of defining a CEAM framework for the Muskoka River Watershed was initiated. The latter involved assessing watershed monitoring indicators, discussing data and communication challenges, redefining the purpose of the program, visioning a stronger monitoring program than was currently in place (e.g., more consistent monitoring and reporting, ensuring trends are identifiable, monitoring with specific goals and decisions in mind, incorporating cumulative effects and climate resilience), and identifying next steps.

The assessment and selection of monitoring indicators followed a new process that emerged from the monitoring program review, discussed further in the results. The process borrowed design aspects from Simple Weighted and Leopold matrices used in Environmental Assessment, scoring criteria that together calculate a rank. A Simple Weighted matrix places environmental components down the left column, project actions (stressors) along the top row, and a score of impact in each intersecting box (positive or negative, from no impact to severe/permanent impact). In Simple Weighted matrices of environmental assessment, ecosystem components are weighted so each score is multiplied by the weight and summed up at the end of each row (Noble, 2006); we did not apply weighting in our study. In a Leopold matrix (Leopold et al., 1971), which is a more comprehensive and commonly-used magnitude matrix, environmental considerations are also along the left column with actions/stressors along the top row. However, components are not weighted, and the intersecting boxes are split (diagonally) into two numbers – magnitude (strength and positive/negative) and importance of the impact (as opposed to importance of the component in Simple Weighted matrices).

Since the indicator selection process aims to prioritize indicators rather than quantify stressors and impacts, the process used in this research used a modified table. Our process includes environmental components along the left column, and criteria for assessing each indicator along the top row. Like in Simple Weighted matrices, a single score is placed in each intersecting box, which is summed at the end of each row (the indicator's total score). The criteria incorporate basic principles of Leopold matrices – importance (of the component) and magnitude of impact – in addition to other principles relevant to the watershed management context (e.g., ease of monitoring).

In the exploratory workshop participants tested the indicator process in a simple exercise to reduce a list of six indicators to a list of five. The starting list consisted of one new/proposed indicator and five existing ones. Existing indicators were chosen by the group from those previously reported in the Report Cards and Background Reports. These were Secchi depth, algae growth, calcium, land use and wetland cover, determined by participants to be critical to understanding both watershed conditions and in some cases climate-related impacts (e.g., algae growth, affected by temperature increases). The new indicator, carbon footprint, was brainstormed by participants as an example of a

**Table 1**  
Sample prioritization matrix adapted from environmental assessment tools.

Criteria (score: 1–5)	Indicator		
	Secchi depth	Algae biomass	Calcium
Cost-effective	4	2	3
Ease of measuring	5	1	4
Important to me	2	4	3
<b>TOTAL SCORE</b>	<b>11</b>	<b>7</b>	<b>10</b>

climate-specific indicator.

We used SurveyMonkey to collect scores for each indicator from each workshop participant, which we then summed up into the matrix exemplified in Table 1. SurveyMonkey was used for ease of response by participants, as well as to ensure participants could not easily track scores across criteria to manipulate scores to individual interests. Each question on the survey was dedicated to each indicator. The following is Question 2 of our survey, with the seven criteria that were used to assess all indicators:

- Rank the indicator ‘secchi depth’ on a scale of 1 (least) to 5 (most) based on the criteria below.
  - I would include this indicator, by this or other name, in the Report Card (e.g. not just in the Background Report)
  - This indicator is measurable given reasonably expected resources (tools, people, funds, time...)
  - We have control over changes to this indicator
  - We have effective mechanisms for correcting CURRENT unwanted changes to this indicator
  - We have effective mechanisms for correcting FUTURE unwanted changes to this indicator
  - Unwanted changes to this indicator would result in serious impacts (directly or indirectly) on ecological and human systems
  - This indicator is important to me

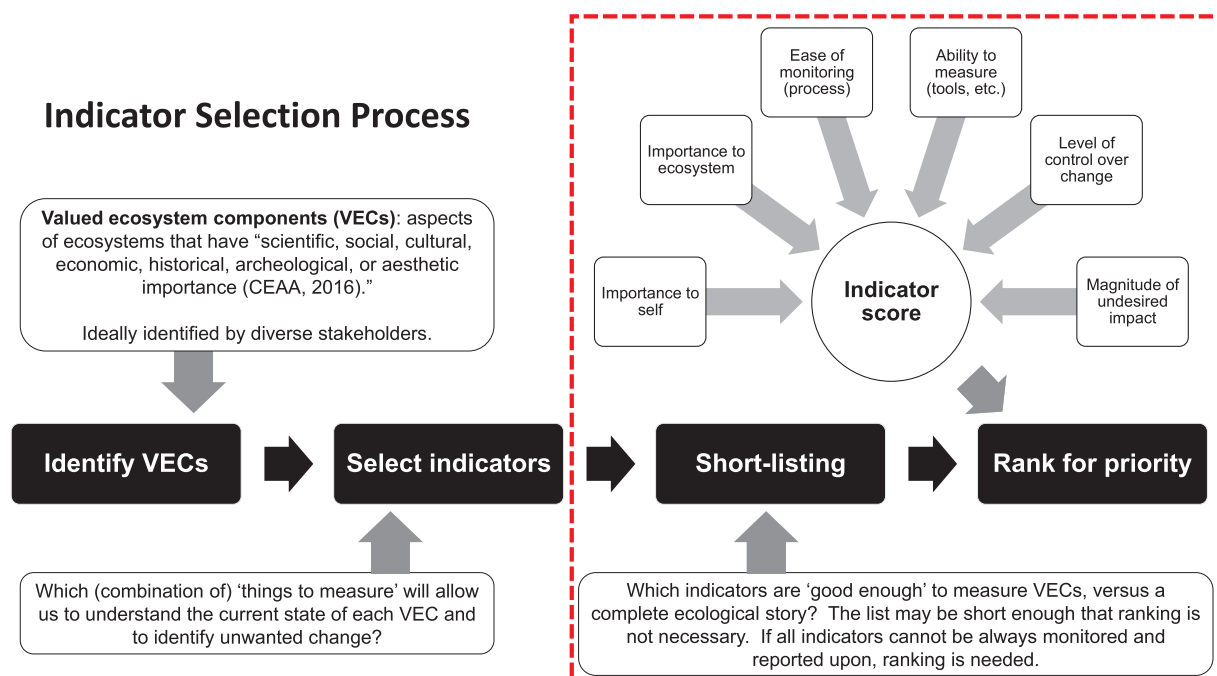
Like environmental assessment matrices, this process is transferable to other contexts. For example, the criteria used for scoring

indicators, and whether weighting is applied (to criteria or components), can be determined for each context. Further, though this process was designed for ranking indicators, the same process can be applied for short-listing a lengthy list of ecosystem components as well. Greater numbers of stakeholders engaged in this process, especially if they are representative of the communities managed, will produce more meaningful and relevant results. The process used for this first iteration of the ranking method for indicator selection are outlined in Fig. 3.

The new indicator selection process was an exercise to provide MWC with a way to prioritize which indicators would be consistently monitored and which would be addressed as capacity permitted (e.g., consistency and a standardized practice improves the quality of monitoring). The process not only identified new potential indicators to address recent challenge or priorities, but also assess existing indicators for efficacy and relevance to current priorities (e.g., how well they address/contribute to our understanding of impacts from climate change). This is especially necessary in contexts like MWC where there is no regulatory structure to ensure consistent human and financial capacities (e.g., funding and personnel likely change year-to-year). In the first step of Fig. 3, Valued Ecosystem Components (VECs), also known as valued components (Bidstrup et al., 2016), are identified. VECs are defined by CEAA (2016). In Fig. 3, and they create a scope for the selection of indicators. For example, a VEC may be edible fish (e.g., something of importance to the community), and an indicator may be levels of lead in fish tissue (e.g., a way to measure impacts on that important thing). VECs may be identified by community or stakeholder groups, or within managerial groups.

Indicators for each VEC are then selected and are sometimes a standard measure of the VEC (e.g., measuring nitrogen is common to achieve the VEC of swimmable waters due to its influence on algae). In the third step, indicators are shortlisted for ranking unless there is capacity to rank all indicators for all VECs. Finally, a set of criteria are ranked for each indicator, which sum up to a final score. These scores prioritize the (short)list of indicators from highest (high score) to lowest (low score). Thus, a standard process of including or excluding indicators ensures degree of consistency despite regular fluctuations in capacity.

For this case study, we used an existing list of VECs already used by MWC in its monitoring. Criteria were weighted equally, since recent



**Fig. 3.** Indicator selection process, highlighted in the box, that emerged from the review. Criteria in the figure are examples of what may be considered.

**Table 2**  
Application of lessons from the Lake Simcoe case study/document review to the Muskoka River Watershed.

Components from lake Simcoe (Pearson and Burton, 2009)	Application to the Muskoka river watershed
Involve stakeholders early and substantively, involve community in climate change planning, and ensure involvement acknowledges diverse community needs.	There is a consensus that some stakeholder groups in the Muskoka River Watershed are not adequately engaged. Also, there remains a need to properly identify target audiences for the Report Cards program, and how to best reach key representatives of them.
Ensure appropriate expertise (capacity) is in place.	The management of researcher turnover and transition of data is a challenge that should be addressed in the future, likely managed by MWC.
Use a range of climate models and scenarios when possible.	Exploration of other programs and tools that can contribute to the monitoring and reporting of watershed health should be pursued, thus using limited resources more efficiently. Similarly, locally available tools and techniques should be used to their full advantage. For example, Ontario has extensive data for use in Ecological Land Classification (ELC) and Ontario Wetland Evaluation systems.
Enable completion of vulnerability analyses.	A concern that was raised during the workshop was that monitoring in the region has been discussed and somewhat implemented in terms of human value – e.g., water quality for human use – beyond indicators of actual system health. Caution should be taken to ensure any implementation of monitoring assesses the needs of the biophysical environment objectively in addition to social needs.
Carefully select brainstorming strategies to match needs, expectations, and time.	Two items that came up throughout the process were the need to create a formal strategy for communication and for prioritizing monitoring activities (e.g., supported research projects, assigning essential indicators).

research concluded that applying weights to individual indicators did not significantly change the results of scoring (Attari and Mojahedi, 2009). As such, the standard unweighted methods were recommended, especially for single-community purposes. However, since each context is different, future iterations should consult with key stakeholders as to whether unequal weighting is warranted. Similarly, criteria for indicator ranking were provided in this case study, though in future iterations these criteria will be designed by the stakeholders.

The exploratory workshop provided a basis upon which to prioritize follow-up discussions and recommended actions. We facilitated discussion of communication methods, indicators and next steps, which initiated a plan for improving monitoring, reporting and educational programs. A key challenge was achieving acknowledgement from workshop participants that not all indicators were possible to address each year (as evidenced by different numbers of indicators having been reported year-to-year). Post-workshop follow-up – conveying survey results, summary discussions, and any changes in recommendations or direction – concluded the study.

### 3. Results

#### 3.1. Monitoring

##### 3.1.1. Results from the literature review, document review, and participation in the CWN-CWRC workshop

A review of literature regarding the application of cumulative effects to water management has led us to conclude that a cumulative effects assessment and monitoring (CEAM) program is likely well-suited to the goal of strengthening MWC's current monitoring. CEAM seeks to not only react to existing concerns, but to prevent future ones. The ability to address potential future impacts is a key tenet of climate resilience. Therefore, strong monitoring programs are needed.

Lessons from Lake Simcoe and Lake Superior highlighted common challenges and potential solutions for strengthening climate resilience of watershed monitoring programs. Components from this process that can be applied more broadly to other contexts include recommendations for stakeholder engagement and communication, objective evaluation of the biophysical indicators, and using a range of practical tools and approaches. The communication of information from researcher to governance body to public needs improvement, as there is no current standardized process. MWC should also identify which stakeholders in Muskoka are willing and able to assume administrative responsibilities and determine how to adapt communication strategies. While MWC

performs monitoring and prepares reporting, it does not make final decisions around resource use or protection in the watershed. This is the role of municipalities and regional (Ontario) government authorities, which need to be well-engaged in the co-creation of monitoring programs moving forward. Recommendations from the Lake Simcoe case study that can be applied to the Muskoka River Watershed are summarized in Table 2.

The report on Lake Superior identified six climate adaptation action categories that may carry over to other regions (Huff and Thomas, 2014). The following points were used as a high-level overview of the strategies recommended in other regions within Ontario:

- Manage non-climate stressors (i.e., invasive species, habitat degradation, etc.).
- Manage habitats, species, and ecosystem functions. The goal here is to sustain native biodiversity, helping biota cope with disturbances from climate change.
- Conserve and connect habitat (e.g., migration corridors).
- Enhance adaptive capacity to take advantage of opportunities presented by climate change.
- Increase knowledge (through monitoring).
- Provide public outreach and motivate action to adapt.

All components were discussed during the final exploratory workshop and are goals underlying the consideration of CEAM in the Muskoka area.

From the review of monitoring and reporting programs, the authors highlighted the high number of indicators (over 50 regular parameters including secchi depth, calcium, temperature, chloride), in addition to many others inconsistently used. The challenge of identifying too many indicators to meaningfully monitor is a common one across Canada, with some programs identifying over 100 indicators (Veale, 2010). In addition to the number of indicators (each of which requires capacity), perhaps a greater challenge is using indicators consistently enough to be able to infer trends and changes. For example, MWC's report cards reported on fish advisories in 2004 and 2010 only, and industrial and automotive emissions in 2004 and 2009. Some indicators weren't reported since 2004 or 2007 (e.g., level of contamination in groundwater), while many others were reported in only one year (e.g., *E. coli*, ozone, waste diversion). Further, ensuring indicators are meaningful (e.g., they are responsive and directly associated with a VEC) requires the monitoring agency to know who will use the information produced from that indicator (e.g., why are we measuring this), which then



**Table 3**

Progression of Development of an Adaptive Monitoring (AM) Framework to Support CEAM (adapted from CWN, 2016b).

Step	Description
1	Develop consistent set of monitoring indicators that will best support effective CE monitoring. <ul style="list-style-type: none"> <li>• Near term, includes (ecological) baseline monitoring.</li> </ul>
2	Develop a series of monitoring <b>triggers</b> for endpoints that allow the monitoring program to be adapted, while maintaining sufficient consistency to allow subsequent steps. <ul style="list-style-type: none"> <li>• Midterm, refine effectiveness and robustness of monitoring approach.</li> </ul>
3	Develop a series of <b>relationships</b> that links the drivers to the responses. <ul style="list-style-type: none"> <li>• Mid/long term, increased focus on ability of monitoring to support adaptive management needs.</li> </ul>
4	Develop a CE assessment <b>model</b> . <ul style="list-style-type: none"> <li>• Long term, enables more effective planning and management decisions.</li> </ul>

provides insight into how to communicate with them.

Muskoka River Watershed participated in a CWN-sponsored initiative to develop monitoring frameworks in support of cumulative effects assessment at the watershed and regional scales. The Canadian Watershed Research Consortium (CWRC) recognized four steps as being necessary in developing true CEAM (Table 3) and supported the development of the first step in six places across Canada including Muskoka. That first step is to develop monitoring indicators and baseline data taking account of spatial and temporal variance. This process, in addition to recognizing the need to develop stressor-effect relationships, may be key to achieving the Muskoka Watershed Council's goals of a healthy watershed and sustainable community as we continue to move towards a climate-uncertain world.

It should be noted that CWRC participants were pleased with what emerged from the five-year (2010–2015) cumulative effects study, and MWC and other monitoring organizations across Canada expressed intent to implement changes based on learning outcomes. However, how much the monitoring program in Muskoka River Watershed will change as a result of its participation in CWRC is not yet known.

### 3.1.2. Results from discussions with subject matter experts, MWC members, and the public

Discussions with MWC highlighted the need for improved data management. Access to original data is often not possible since the data are often held privately by the individuals who collected them. Over time, keeping track of who has what data becomes more difficult, especially since there is usually no obligation by the researcher to maintain communication with MWC on the status of data (e.g., the researcher may choose to destroy a dataset that has not been worked on for years). New requirements by many journals to provide original data are one answer to this problem and another reason to publish research results in the primary literature.

Because MWC relies on partnerships with other institutions and organizations for much of its research, some research is completed during short-term commitments (e.g., < 5 years) from university researchers or other organizations (e.g., CWN). Longer-term commitments for monitoring appear to come from government employees or partially-retired academics who volunteer time as MWC members. However, the core group of MWC volunteers has limited capacity to address multiple issues across the whole watershed. It is likely this turnover rate of researchers and monitoring individuals is greater in Muskoka than in areas with Conservation Authorities due to the lack of dedicated staff for ongoing watershed programs (e.g., monitoring).

In the Muskoka River Watershed, concerns about inconsistencies in data collection and analysis were expressed by MWC members, though we were not able to discern what those inconsistencies were due to the lack of access to original data. A standard methodology for collecting data that can be followed by successive researchers, whether scientists

or community members, is recommended. Further, calibration exercises are needed when processes in data collection or analysis change. For example, in the last few years, Fisheries and Oceans Canada's Community Aquatic Monitoring Program, which offers guidance for monitoring activities to follow across Canada, changed their procedure from collecting unfiltered water samples for nutrient analyses to collecting filtered water samples. Further, the lab that processed samples was changed. This prompted a calibration exercise to allow new data to be compared to old (Thériault and Courtenay 2012). MWC members indicated that studies of a single parameter (indicator) sometimes occurred in different locations from year to year. Consistent indicators and data collection methods ensure comparability (inferring trends) between reporting years and replicability of the data (Veale, 2010).

After reviewing the literature and case studies, discussing with key stakeholders, and receiving feedback from the community, a preliminary CEAM framework emerged for the Muskoka River Watershed. As CEAM improves our ability to identify issues – such as undesirable changes to predetermined aspects of the system (indicators or VECs) – we are more capable of adapting our practices to address climate change. This increases the resilience of the watershed and its local communities. In the future, other complementary actions (e.g., vulnerability analyses) may also be effective as decision support tools (Glick et al., 2011; Lemieux et al., 2014).

### 3.1.3. Results from the exploratory workshop and new indicator selection process

This exploratory workshop generated useful discussion around data collection (e.g., which parameters were effective and important), components of a monitoring program (e.g., whether to define triggers for action) and the communication of monitoring outcomes (using the Report Cards and other methods). Regarding whether to include monitoring triggers as part of MWC's monitoring program (currently not included), discussion around what would qualify as a trigger created some disagreement. There was general (not total) acceptance that a perceived trend, rather than a firm threshold or limit, should be used as a trigger. The triggered action would involve either heightened attention to the indicator, or remedial action, and any changes would be assessed as either desirable or undesirable. Demonstrating change, relative to the previous state of the watershed recorded through Report Cards, would improve management responses, and provide an assessment of the effectiveness of management responses, when needed.

The challenges of indicator quantity and quality were discussed with stakeholders throughout the study, especially during the exploratory workshop. The general view from science-oriented stakeholders was that ecological systems are complex and so indicators should not be simplified or reduced. Participants with a more political point of view, and those concerned with the economics of the monitoring program, generally agreed that maintaining a consistent set of indicators for ongoing monitoring would require refining and, likely, reducing the number of indicators currently used. The idea of keeping current indicators, and finding ways to maintain current capacity (people, funds, technology), was briefly discussed before a consensus was reached: the current set of indicators needed revision.

Conventional ways of choosing indicators – discussion among MWC members – did not seem to be an efficient way to make significant changes to this long-standing monitoring program. Instead, the new process for indicator prioritization developed in this study (Fig. 3) was tested. The indicators portion of the exploratory workshop focused on testing this new process. As such, the selection of indicators for use in this process was brief for the sake of the exercise. A separate meeting was to be convened at another time to focus exclusively on updating/refining the indicators list, including discussion on what is being measured and standardizing data collection techniques.

When a common set of criteria (e.g., outlined in Section 2.3) was used to assess indicators, a different set of indicators emerged than the set created without common principles to guide MWC's assessment.



**Table 4**  
Results of the indicator prioritization exercise.

Criteria	Indicator <sup>a</sup>					
	Secchi Depth	Algae	Calcium	Land Use	Wetland cover	Footprint (new)
I would include this indicator, by this or other name, in the Report Card (e.g. not just in the Background Report)	17	31	23	33	32	27
This indicator is measurable given reasonably expected resources (tools, people, funds, time...)	33	22	25	30	25	20
We have control over changes to this indicator	18	20	18	27	24	23
We have effective mechanisms for correcting CURRENT unwanted changes to this indicator	16	19	16	25	19	20
We have effective mechanisms for correcting FUTURE unwanted changes to this indicator	20	21	17	27	21	20
Unwanted changes to this indicator would result in serious impacts (directly or indirectly) on ecological and human systems.	22	31	27	31	28	30
This indicator is important to me	24	31	25	34	31	28
<b>TOTAL SCORE</b>	<b>150</b>	<b>175</b>	<b>151</b>	<b>207</b>	<b>180</b>	<b>168</b>
<b>Rank – short-listed?</b>	<b>6 – No</b>	<b>3 – Yes</b>	<b>5 – Yes</b>	<b>1 – Yes</b>	<b>2 – Yes</b>	<b>4 – Yes</b>

\* Scores are the sum of individual participants' scores for each criterion.

During discussions, Secchi depth was the one indicator that the group felt was sure to make the list as a key indicator. However, after assessing the indicators through the new process, the results ordered the top five indicators as land use, wetland cover, carbon footprint, algae growth, and calcium; Secchi depth did not even make the list (Table 4).

Data management was briefly discussed and led to a consensus that a meta-database should be considered to reduce duplication of research and monitoring, identify gaps in research and monitoring, and to make data more easily accessed over longer periods of time. A meta-database would include descriptors on what data were collected, when, where, by whom, and contact information (e.g., an email). Other information discussed included where the data are stored, if they are accessible (e.g., private or public), and methods of collection. In addition, workshop participants concluded that a data repository would not be within their current capacity.

The need to clarify monitoring and reporting program goals was a major takeaway. Why these programs existed, the goals or intended outcomes (e.g., what they hoped to achieve), and the target audiences were unclear at this stage of the programs' evolution. Lack of clarity was due to the programs and organization expanding, increasing in capabilities, and needing to update their mandates. Workshop participants identified key challenges and discrepancies, and MWC proceeded to address them after the study was complete.

### 3.2. Communication

#### 3.2.1. Results from the literature review and document review

The majority of results related to communication came from the document review of the Report Cards, though literature and discussions with MWC offered some insight. Participation in the CWN-CWRC workshop did not inform analysis on communication of monitoring/educating the public on watershed issues, other than to acknowledge that inconsistent monitoring and reporting occurs across the country.

Sale et al. (2016) identified issues with communication strategies used by MWC, including an underwhelming web presence and that the Watershed Report Card system is likely under-used. Insights from Lake Simcoe (Pearson and Burton, 2009) and Lake Superior (Huff and Thomas, 2014) highlight the importance of effectively presenting summary information about the state of the environment to community members and local stakeholders. As MWC is currently looking to integrate climate change considerations with the existing watershed health report, attention is needed to ensure monitoring and communication tools are used effectively. Our literature review concluded that diverse collaborations, in which community members are regularly informed and involved throughout the monitoring and decision-making process, may facilitate Muskokan residents taking steps towards climate

resiliency (e.g., reduce their carbon footprint in the watershed and be prepared for likely changes).

For Muskoka River Watershed, the document review of Report Cards highlighted issues with monitoring communication and community engagement/education. Information on how the data were collected and analyzed is not included in the Report Cards, nor are most of the actual measures (e.g., the amounts of nutrients in the water) or observed trends (e.g., the graphs). MWC designed Report Cards to be a very concise, plain-language snapshot of the current state of the watershed, and so the bulk of the information is found in the Background Reports.

The Background Reports are a combined 320 pages of somewhat-simplified scientific dissemination accompanying the Report Cards, all of which are accessed through the MWC website (see Table 5 in the Supplementary information). Like the Report Cards, these were presented (e.g., structured) differently each year they were produced. For example, the 2004 Background Report was split into eight separate reports tackling separate issues, e.g., swimming, fishing, or land use. Each of these reports included information on the state of the watershed, measurements taken, implications of each indicator on system health, and actions recommended by both water managers and community members. Summary tables were used to summarize in the information. Then, in 2007, a single Background Report was generated without the use of summary information, though the incorporation of 'action' boxes next to each issue presented was a useful addition. The most recent report in 2014 was organized into seven groups of indicators, with sub-indicators within each group. Summary tables, including comparisons between 2010 and 2014, were used, and trends were color coded.

Despite inconsistencies with the Background Reports, they were generally comprehensible and ultimately contained the same basic information (e.g., what was measured, what were the numbers). The Report Cards were less effective as a communication tool. When all Report Cards were considered together, there was not enough congruence or continuity in the communication of indicators, symbols, and measurement units to infer trends or changes in the state of watershed health. As noted in the report submitted to MWC (Ho et al., 2016), the lack of a coherent story between report cards is partially due to the inconsistent organization of the same monitoring indicators into different categories by different names from one Report Card to another, or the reporting of different indicators altogether.

Table 6 in Supplementary information describes the factors/metrics described in the 2004, 2007, 2010 and 2014 Report Cards, as well as the 2009 Progress Report. Only information presented in the Report Cards was used in the communication review, for two reasons: community members do not typically read the Background Reports, which

are long and scientific, and the Report Cards were initially designed to be a stand-alone communication program, with Background Reports providing context, methods, and more detail.

In addition to the actual content, Report Cards were assessed for overall efficacy in communication (e.g., visuals, layout, and organization of sections). The layout and design of each Report Card was significantly different than the last, making them hard to compare side-by-side. Implications of information presented in the Report Cards for community members were also unclear, which made them less personally relevant to locals. The challenge of reaching the intended audience effectively is mitigated by clarifying who the target audience is prior to initiating reporting.

High-level results included that the shift to more contrast and better visuals made the cards more appealing, with less paragraph-style information and more graphical information (e.g., color coding maps). Simpler graphics and calls to action (with explanation as to why/what the implications are) appeared more effective. For example, the 2010 card used the wording “Help protect...” and listed some valued aspects of the water system, as well as what could be done. This was written in a more engaging and positive way than the “What can I do” section of the 2004 card, which had little explanation or context, making the call to action seem more random and less meaningful.

### 3.2.2. Results from discussions with the public

Engagement with the community on the topic of communication was limited to residents who spoke with us at the Muskoka Summit on the Environment. These residents were informally gauged (e.g., through casual conversation on the general topic of watershed health) for their awareness of MWC, its monitoring program, and if they have ever read a watershed Report Card. As attendees of the Summit these residents are more likely to have engaged in the health of their local environment, but despite this bias some had not ever read a Report Card. Each of the residents who had not read a Report Card expressed interest in reading it, they had just never heard of the program before.

### 3.2.3. Results from the exploratory workshop

The third step in our methodology was to facilitate discussion with MWC members at an exploratory workshop dedicated to monitoring (which was discussed above) and communication. Goals of communication in Muskoka River Watershed include education of the public and engaging them in changing behaviours. A separate context of communication is to influence decision-makers, but this was not included in our study.

Discussion with MWC members concluded there was no clear strategy for communicating the results of their watershed monitoring. Participants agreed a formal (ideally written) strategy for communication would be helpful. This communication strategy would define the mandate of the monitoring communication program(s), identify the target audience(s), and include ways to reach and follow up with them. Regarding the Report Cards themselves, it was agreed that refining the indicators was necessary, including selecting which ones tell a story for public reporting purposes. Since the Report Cards program was set up with Report Cards and accompanying Background Reports, workshop participants discussed reporting on only a few key indicators in the Report Cards (e.g., which tell a story/represent a trend, that the community would be most interested in) and leaving the rest for the Background Reports.

## 4. Discussion

The need to build climate resilience into all aspects of society, including water management, is the result of a recent shift in efforts to address climate change. Focus has moved from mitigation, or, reducing the effects of a new climate regime (e.g., keep warming to 1.5 degrees Celsius), to adaptation, e.g., changing our infrastructure and management practices to increase resilience to extreme weather events (i.e.,

construct buildings able to withstand hurricane winds, or managing dams and water flow to accommodate extreme precipitation) (Government of Canada, 2015). This shift is evidenced by recent actions like the Vancouver Declaration, signed by leaders of provincial and territorial governments on March 3, 2016.

As focus on potential impacts of climate change increases, many regions (e.g., Lake Simcoe, Lake Superior) are integrating climate change adaptation into current decisions (Huff and Thomas, 2014; Lemieux et al., 2014). This is the context surrounding MWC's goals to strengthen monitoring and improve communication with, and education of, its communities. Information gleaned from all three steps of the study are found in each of these subsections.

### 4.1. Monitoring

#### 4.1.1. Discussion of outcomes from the literature review, document review, and participation in the CWN-CWRC workshop

Addressing MWC's monitoring program is an effective way to ensure maximum reach (decision-makers and community members alike) without detracting from MWC's core mandate. The literature has demonstrated that monitoring programs have the potential to influence change in the governance of water systems by improving decision-makers' understanding of how the system works, and how it reacts to stress (Lindenmayer and Likens, 2009; Smith and Stirling, 2010). As MWC has identified, monitoring programs can also fill the role of educating the public with the intent to influence individual-level behaviour. However, improvements to current monitoring are needed to increase the potential impact the program can have.

During the literature review, we took lessons from two other watersheds in Ontario: Lake Simcoe and Lake Superior. We acknowledge these regions are not precisely comparable to the Muskoka River Watershed (one could argue no two systems are the same). Lake Simcoe, managed by the Lake Simcoe Region Conservation Authority, is much more populated than the Muskoka Region and receives some of the greatest provincial funding of any watershed in Ontario. Lake Superior is the largest of the Great Lakes, and Canadian and US municipalities or regions each have different regulatory and non-regulatory management systems in place. However, many of the challenges and goals of monitoring programs in all three regions we have discussed (Simcoe, Superior, Muskoka) – and elsewhere in Canada – are the same or similar (Veale, 2010). Thus, much of what is learned in one context can be applied, with some tailoring, to other watershed contexts.

To highlight this point and to provide some insight from a ‘best practice’ in water monitoring, we can consider the Healthy Land and Water (HLW) program based in Brisbane, Australia. The area HLW monitors includes all South East Queensland's waterways (e.g., creeks, rivers, estuaries, bays, catchments), which are found in or near high-populous communities (e.g., Brisbane's 2.5 million residents compared to Muskoka Region's 60,599). HLW has recently revised its watershed monitoring and reporting programs to accomplish similar goals to those of the Muskoka region: improved ability to identify and mitigate increased and more complex environmental pressures; improved socioeconomic benefits of waterways to communities; and to consider multiple pressures on the watershed (Healthy Land and Water, 2017a,b; Moreton Bay Regional Council, nd).

Key aspects of the HLW aquatic monitoring program include: annual or more frequent reporting of water quality parameters at more than 200 freshwater, estuarine, and marine sites; improved indicators list, including a priority short-list, to ensure consistent stories can be told; simplified reporting (letter grades and a five star socioeconomic benefits rating) based on the two main goals of increasing environmental health and maximizing socioeconomic benefits for the community; easily navigable by the public using an interactive map and pinpoints for various components of watershed health; and highlights of local actions, including featured awards (Healthy Land and Water, 2015). Information emerging from HLW's monitoring program provides

critical decision support by informing priority actions and tracking and setting targets to achieve watershed goals (Moreton Bay Regional Council, nd).

Adopting a CEAM program in Muskoka River Watershed would require improvements in the way data are prioritized, collected, and stored for potential future use. The document review revealed monitoring inconsistencies in what was measured (e.g., how much and which indicators) from year to year, affecting the usability of data in analyses. Finer, more detailed data are usually needed to account for effects across scales (e.g., accumulation of nutrients from surrounding land use over space and time) and are one of the main deficiencies in many monitoring programs (Bidstrup et al., 2016; Ball et al., 2013). When data from monitoring programs are used frequently, properly, and in a timely manner, identification of early warnings and emerging challenges is possible, resulting in a more resilient system (Healthy Land and Water, 2015). Researchers and monitoring bodies in any context need to agree on what should be measured and how, and MWC is no exception.

For the small group of volunteers at MWC, data challenges include limited capacity to address all issues across the watershed at all times (e.g., cost, personnel, time), unstandardized data collection methods, uncertain access to individually-held data, and the high turnover of research personnel. Yet another challenge, in addition to maintaining consistent data collection, analysis, and storage, is that individuals will interpret data differently from each other. An example from Greig and Pickard (2014) demonstrated that giving the same dataset and broad purpose to a group of people can result in different interpretations of the process to be followed, which changed monitoring outcomes.

A central metadatabase, especially one that encourages consistency in the storage of data between organizations and institutions, will improve accessibility and transparency of data sets (Sale et al., 2016). Benefits of a metadatabase may include the minimization of monitoring costs and the reduction of effort duplication (i.e., unnecessary, or redundant activities). In addition, a metadatabase can be used as a tool to enhance continuity between successive researchers so as not to reinvent or diverge from the current monitoring program every time researchers change. Some Conservation Authorities in Canada (e.g., Grand River) make use of WISKI – Water Information Systems by KISTERS. This tool provides unlimited storage of raw and processed data, helps to organize data, automatically generates a metadatabase, maps data collection, and more. Despite these features, a limitation of this and other similar systems is an inability to identify, visualize and analyze cumulative effects. To address this gap, a new software called THREATS – The Healthy River Ecosystem Assessment System – was announced by the Greenland Group of Companies in 2017. THREATS compares monitoring data to reference conditions, which are based on indicator ranges (e.g., describing a distribution rather than an absolute value), and uses three tiers of decision trees to demonstrate movement of parameters to or from those reference conditions (Dubé, Nadorozny and Squires, 2011).

Solutions like WISKI and THREATS are likely not practical for the Muskoka River context due to cost and maintenance requirements, as well as the need for original data in order to generate the metadatabase. Considering the current capacity of MWC, a basic metadatabase (as simple as an online table with the required information presented) is likely the most effective way to initiate this practice.

MWC is a multi-stakeholder organization with a mandate to ‘champion’ and monitor watershed health, and so the most logical host of a metadatabase; however, taking on this initiative would require administrative capacity and funding, as well as buy-in from regional monitoring bodies and regulatory bodies responsible for watershed management. Thus, an alternative may be to approach a regional office (e.g., Ontario Ministry of Environment and Climate Change, or Ontario Ministry of Natural Resources and Forestry). MWC and other watershed stakeholders will need to determine who will be accountable for implementing and maintaining data solutions.

Engaging with decision-makers on the topic of data management is beneficial to all parties involved. Information pertinent to the broad needs of decision-makers can be produced by monitoring programs. Data emerging from well-developed monitoring programs are valuable to understand the various natural cycles and exchanges – the movement of energy and matter (e.g., nutrients like carbon and phosphorous) within and between ecosystem (Delphis et al., 2011) – that occur between land, water, and air. However, the data must be analyzed to assess changes and trends that may become triggers for a change from ‘monitoring only’ to ‘monitor, act and follow up’ (Dubé, 2015). This is what can inform management and policy strategies. Information is only as useful as the actions that follow.

Examples of management strategies following the implementation of CEAM include avoidance and mitigation (e.g., preventing or minimizing the impact of stressors), compensation (no-net-loss, e.g., creating a new wetland when one is lost), implementation of trigger-based monitoring (e.g., require follow-up at earlier and more frequent points of monitoring), and/or revise rules at the strategic level (Therivel and Ross, 2007). Other improvements are needed to identify reference conditions (which do not necessarily mean pristine conditions: Dubé, 2003; Dubé et al., 2013), indicator parameters, and scales for cumulative effects (Ball et al., 2013; Eimers, 2016).

#### 4.1.2. Discussion of outcomes from discussions with subject matter experts, MWC members, and the public

Watershed monitoring programs should be designed to handle spatiotemporal scales, complex system responses, and natural variability (Arciszewski and Munkittrick, 2014; Ball et al., 2013; Eimers, 2016). CEAM is ideal for regional scales, with implications that are relevant for watershed-level management decisions (Chilima et al. 2013; Kristensen et al. 2013). Cumulative effects monitoring can also involve the public (Jones, 2016). Whereas current monitoring focuses on one or a select few stressors in a limited timeframe and in a certain environmental context, CEAM considers past, present, and potential future stressors (long-term timelines) and their relationships and synergies (INAC, 2007; Northwest Territories, 2015).

The adoption of a CEAM program for the Muskoka River Watershed is aligned with current efforts and literature from across Canada and is supported by the CWN-CWRC initiative. However, despite rapidly growing interest to consider CE in watershed and water monitoring, CE is not yet broadly considered in monitoring activities. As we engaged with subject matter experts, MWC members and the public, we noticed three main challenges. First, CE concepts seem to develop slowly. The field of CEAM is jargon-full, making it inaccessible to many. This results in the need to constantly redefine terminology to ensure all individuals at the table are speaking the same language.

Second, there is a lack of standardization in the implementation of CEAM, in part due to lack of good examples. Unstandardized approaches result in the theory appearing inapplicable to real-world contexts. Most local authorities do not have the resources to invent and test an entirely new monitoring framework. Further, when responding to climate change concerns, it is unrealistic for most local authorities to implement an unproven framework that needs years of testing and adaptation before deciding whether it should be permanent; this is time that is just not available when responding to immediate concerns.

For those wishing to implement a CEAM process, Jones (2016) outlined seven steps that may be applied to a general context: identify VECs, define boundaries, characterize the ecological baseline, analyze predictive CE on VECs, determine the significance of effects, and monitor outcomes and performance. Public engagement is meant to be integrated throughout CEAM, with maximum benefits occurring the earlier public engagement occurs (Eimers, 2016; Jones, 2016). Implementing CEAM effectively for the purpose of climate resilience requires the development and delivery of data-related programs (e.g., monitoring and reporting programs) to be guided by the needs of stakeholders (Morand et al., 2015).

Finally, while some authorities and policies recommend CE be considered in monitoring programs (INAC, 2007; Northwest Territories, 2015), mandates and guidelines offered through legislation need improvement. Without the requirement to consider CE, it is up to local leaders to take the initiative – if determined it is appropriate for their context.

#### 4.1.3. Discussion of outcomes from the exploratory workshop and new indicator selection process

One of the basic (data) questions of any monitoring program, including MWC's, is what should be monitored. This is followed by where, when, and how to monitor (Arciszewski and Munkittrick, 2014; Ball et al., 2013; Greig and Pickard, 2014; Lindenmayer and Likens, 2009). As described in results Section 3.1, inconsistent monitoring and reporting are challenges common to many contexts (Veale, 2010). A study of multiple watersheds by Ball et al. (2013) concluded that monitoring programs used a range of indicators with little standardization between them, though nutrients were considered in every program studied. A concern here is the reliability of indicators, whether they provide the information expected (Arciszewski and Munkittrick, 2014; Greig and Pickard, 2014).

In addition, bias exists from individuals who are at the table to determine which indicators will be measured, but who do not represent all stakeholders in the watershed. Thus, the selection of what to sample may hinder the program's ability to detect effects, though this risk may not even be recognized consciously (Greig and Pickard, 2014). The indicator prioritization method we developed and tested during the exploratory workshop is one way of addressing this bias. By ensuring indicator assessment criteria represent diverse perspectives, the representativeness of individuals assessing/selecting indicators is less important. This is not to say the criteria we used were perfect. Rather, using broad (e.g., ecological, socio-political, economic) criteria agreed-upon by diverse watershed stakeholders is more likely to result in a list of indicators that responds to multiple needs and addresses multiple issues than without assessment criteria. Similarly, it is possible these criteria may direct monitoring to produce information more relevant to decision-makers, but this was outside the scope of our study.

Implementation of a metadatabase was a recommendation intended to connect the two goals of this study – strengthening the monitoring program and improving communication with/education of the community. A metadatabase will require ongoing buy-in and collaboration from stakeholders in the watershed, as well as achieving consensus on how to minimize overlap (excluding duplication for validation or confirmation purposes). Once a metadatabase is implemented, it should be used to assess whether current and proposed research is needed or if it is redundant. A concern for MWC and many others implementing similar programs is that data collected do not adequately address the needs of those managing the resource. This supports the need to identify appropriate monitoring indicators, in tandem with ensuring researchers, citizen scientists and resource managers are all aligned in the purpose and direction of data collection.

## 4.2. Communication

#### 4.2.1. Discussion of outcomes from the literature review and document review

Influencing behavioural change using data from watershed monitoring requires a coherent storyline with consistent communication of what was measured. In the case study, easily understood units that are consistent, and fewer indicators being communicated (despite how many are measured) in both the Report Cards and the Background Reports, would make the information shared much more digestible to the public. The background reports were likely overwhelming for the average community member, but are useful for monitoring and, to some extent, decision-making purposes. Plain language communication of specialized knowledge is crucial to educating the community, garnering

support and ensuring the most successful implementation of policies and strategies (Bishop et al., 2015). Results of a study reviewing monitoring programs across Canada (Veale, 2010) are consistent with our results from the Muskoka study. Veale (2010) concluded:

1. Issues discussed should be stakeholder-determined;
2. Measures and indicators should be consistent;
3. The number of indicators should be limited, and formats simple;
4. Measures should be temporally relevant, science-based and spatially-explicit;
5. Explain major cause-effect relationships;
6. View the report card process as a means by which to build support;
7. Incorporate marketing and outreach; and
8. Ensure performance measures to assess how effective the program is.

Watershed report cards have a multi-purpose role as a tool for communication which then influences planning, assessment, involvement, learning, and research (Veale, 2010). With CEAM, multiple factors are considered as part of an integrated web of mutually impacting factors, and so the types of things measured may change compared to current monitoring efforts. As such, it is possible, though not true in every case, that the use of CEAM may change the format of a state-of-the-watershed report card. A report card can still offer categorized snapshots of current state without segregating individual indicators – as current MWC (and other) report cards do. The HLW example demonstrates how an aquatic monitoring program can evolve to consider CE while maintaining congruency in reporting. HLW's monitoring shifted from segregated indicators, to integrated aquatic indicators, to comprehensive land–water indicators.

#### 4.2.2. Discussion of outcomes from engagement with the public, and from the exploratory workshop

Cumulative effects have been increasingly considered across Canada through successive iterations of monitoring programs, demonstrated by changes in the indicators monitored and the way data are used (e.g., analyzed and applied to decision making). As with any research project, a common understanding of the story being told (e.g., which trends are being communicated and how), and a clear vision regarding how the data will be used, are important precursors to the design of successful watershed monitoring and reporting programs. Understanding the end-users (e.g., who they are and how to reach them) is critical to ensuring they are reached. Similarly, follow-up should occur to assess whether communication is effective (e.g., are people reading your Report Cards and finding them useful?).

The 2018 Watershed Report Card – MWC's first Report Card since this study was completed – demonstrates many changes that reflect the review and recommendations presented in this paper. First, fewer indicators are reported upon: four indicators of health and four indicators that measure potential threats. Health indicators are total phosphorus, calcium, benthic macroinvertebrates and interior forest cover. Threat indicators are climate change, species at risk, invasive species and (habitat) fragmentation. Second, cumulative impacts are discussed with the community, although not necessarily measured through monitoring. For example, for the species at risk indicator, MWC points to multiple interacting stressors to answer the question “Why are these species at risk?” The response includes various types of habitat loss and fragmentation, competition from introduced species, traffic mortality, illegal harvesting, disease, pollution and other stressors. Similarly, for climate change, multiple potential impacts from climate change as a stressor are discussed, including potential flood, drought and fire risk, habitat degradation and warmer waters, which cumulatively result in impacts like lower fish spawning rates (and other impacts mentioned).

Third, the 2018 Report Card includes two very accessible formats: infographics and story maps. Whereas older versions of the Report Card and Background Report were primarily text with accompanying visuals



(if any), the 2018 Report Card incorporates an infographic per indicator into one general Report Card (e.g., a *Summary Infographic* for the whole watershed) and into multiple quaternary/subwatershed Report Cards (formatted consistently). The Background Report is now 99 pages of much more accessible language, in a layout that makes more sense to a broad audience (e.g., fonts, spacing, visuals, colors, headings).

The story maps are an entirely new multimedia format of the Report Card. For the general Report Card screen, there are navigation tabs along the top and a split screen with descriptive content on the left and media – videos, photos or interactive maps – on the right. Tabs include a welcome screen, an about page describing what watershed report cards are, a page justifying the reason for them, a very brief summary of findings (like an abstract), a tab defining watersheds, a tab to help the public locate themselves in one of the quaternary subwatersheds, a ‘Dive Deeper’ page linking to story boards for each of the eight indicators and a final screen with high-level calls to action. Individual indicator story boards navigate down the side pane with media on the right. Indicator storyboards incorporate six types of content (number of sections varies):

- About the indicator, e.g., what it is and why it matters
- How the indicator is measured by MWC, including data sources
- Interactive reporting map stating and color-coding the grade of each area monitored – stressed, vulnerable, not stressed
- An interpretation of what the grades mean for the community and ecosystem
- A ‘Local Spotlight’ highlighting positive actions by a local person or organization
- Specific calls to action related to the indicator being discussed

Finally, dissemination of the 2018 Report Card is also improved. Prior to the release of the Report Card, a series of blog posts were shared on MWC’s website to explain monitoring goals, the new direction and format of the Report Cards, and to educate the community on why the specific indicators matter. In addition to the two formats – infographics and story boards – MWC hosts booths at events to reach out to the community and has added hard copies of the infographic Report Cards to various venues around the Watershed (e.g., a new Watershed Wonders exhibit at the Muskoka Discovery Centre).

However, despite huge strides improving communications, the processes behind the monitoring program still have room for improvement. To build climate resilience in the Muskoka River Watershed, all stakeholders need to be represented in the process. For example, participatory approaches for monitoring, consultation, decision-making, etc. may be used. This is an objective of the MWC, though so far engagement has been restricted to informing the public, not engaging them in co-creating monitoring programs and outcomes (MWC, 2016b).

Developing ownership of a monitoring program by the community results in higher levels of effectiveness and success and should be considered when changes from community members are needed (Ho et al., 2016; Hogg et al., 2012; Reed, 2008). A key consideration here is to ensure the theories and practices that are the foundation of water monitoring and management are understood well enough to ensure meaningful participation. A dedicated training/education program for non-science individuals is likely needed and is suggested to be undertaken by a partner of MWC. It is important for community members and local stakeholders to understand environmental changes happening over time for reference and education. In this way, report cards can facilitate behavioural change and spark interest in local sustainability initiatives (Veale, 2010).

Finally, the indicator prioritization process should be further developed in other contexts. Future iterations may assess whether weighting of criteria is warranted in specific contexts. Further, whether criteria should be standardized or specific to individual cases may also be explored. Of the criteria used in this study, we suggest also

incorporating ‘measures of success’ – for example, incorporating the criterion of ‘efficacy’, ‘reach’, or ‘influence’, evaluating whether the target audience (e.g., decision-makers) is actually reading or considering information reported from the monitoring program.

In the same way indicators may need to be prioritized in times of fewer resources, monitoring practices may need to be assessed so that data collection sites are coordinated with prioritized indicators. For example, an indicator may not be ideal to measure the way it currently is (e.g., method and locations); however, another indicator studied at strategic locations may still provide desired insights. Alternatively, some monitoring programs use a consistent set of indicators but will do a rotation of sites across years. For example, in the Northumberland Strait estuaries (Gulf of Saint Lawrence in eastern Canada), eelgrass is measured in five estuaries per year on a five-year rotation so that the 25 estuaries are covered in a five-year period. Considering changing indicators and sites together may improve cost-effectiveness and encourage the addressing of cumulative effects.

## 5. Conclusions

Our climate is changing at an unprecedented rate, with impacts already being felt in social and ecological systems around the world. Muskoka Watershed Council (MWC), a multi-stakeholder group concerned with monitoring and reporting on the health of the Muskoka River Watershed, has prioritized climate change as a key issue to address in the coming years. Although the MWC does not itself have decision-making power in the region, it influences watershed authorities and policy makers based on information from its watershed monitoring activities.

This study guided the planning of next steps and future actions in the Muskoka River Watershed. Insights may inform other watersheds in Canada with similar goals. Gaps and opportunities for research and practice were also identified while addressing the following two recommendations from Sale et al. (2016):

- 1.a. *Strengthen and broaden the existing monitoring of lakes in Muskoka; and*
- 2.a. *Every individual Muskokan should undertake to become informed on climate change issues, and take real steps to reduce his/her own carbon footprint.*

We should point out that although we assisted MWC in brainstorming and planning for future steps, we have yet to see how much of what we presented in this paper will be implemented. As a result of this study, MWC made great progress in its Report Cards program, however the impacts of these changes are still being measured (e.g., 2018 Report Card was released in July 2018). Further, MWC continues to review its monitoring program and whether/how to incorporate cumulative effects.

Regarding watershed monitoring, two recommendations were given. First, a cumulative effects assessment and monitoring (CEAM) program should be implemented, including the clarification of indicators and their consistent use and measurement. Current monitoring would need to be refined to ensure that data being measured are used, and that only usable data (implying an understanding of data needs) are measured. The new approach for refining the set of VECs or indicators used in monitoring can be a helpful tool for incorporating broad considerations into VEC or indicator assessment. However, to be effective, criteria used to assess (or score) each VEC or indicator need to be carefully selected, ideally through consultation representative of all stakeholders. Second, an easy-to-use metadatabase should be put in place.

On the topic of community education, information should be communicated so that both decision makers and community members may understand and consider past, present, and future implications. Generating and implementing an ongoing communications strategy includes ensuring consistency and continuity between Watershed Report Cards so community members can infer trends and implications. Implementing these

recommendations may allow more comprehensive social-ecological relationships to be understood, especially those that surface over spatial and temporal scales. Decision-makers will be better equipped to address potential risks from climate change and other stressors, increasing the resilience of watershed communities. The narrative carried through successive Watershed Report Cards will be more compelling, and the community is likely to be more engaged in changing behaviour.

Building on the current mix of MWC programs to create a more integrated suite of monitoring and reporting programs (and advisory practices) is a valuable step for the Muskoka region to consider taking. While interest in considering CEAM continues to grow, the practice itself is slow to develop. Reduced or, at minimum, standardized jargon would address this concern, whereas a formal mandate to seek out, implement, and learn from examples of CE as part of or as the primary aspect of (aquatic) monitoring programs would initiate growth and development of the practice.

In other words, more pioneers of CE examples are needed, and the Muskoka River Watershed may be a leader should the recommendations discussed in this paper be implemented. We recognize the scale and complexity of this task, which would be a substantial undertaking to implement and maintain. However, dividing this task between collaborators from the community and other stakeholder organizations may increase the viability of implementing CEAM. This is especially true where collaborations coordinate allocation of resources to ensure more efficient use of people and funds across monitoring and reporting efforts. While a challenge, collaborations under frameworks like CEAM are increasingly necessary worldwide.

Our results align with challenges and observations that emerged from other recent case studies across Canada and the world. By improving multi-stakeholder engagement and encouraging the continuation of this research in greater depth, we hope to see positive impacts across multiple jurisdictions. Addressing climate change requires bringing together learning from disciplines and case studies from around the world. We propose a climate-resilient watershed management practice, informed by CEAM (the framework developed by CWRC) to devise monitoring indicators, integrate and streamline metadata and solidify a communication strategy to report and disseminate. In these ways, we hope to contribute to a more resilient future of aquatic monitoring in Canada and abroad.

Original data are not being made available as they were part of a confidential review to improve the practice of the Muskoka Watershed Council. Further, data that are not available are specific to the context of the case study. This manuscript represents a complete evaluation of the case study and includes any information relevant to other contexts.

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <https://doi.org/10.1016/j.ecolind.2018.08.017>.

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